THE OHIO JOURNAL OF SCIENCE

VOL. XLV JANUARY, 1945 No. 1

THE USE OF WEATHER BUREAU DATA IN ECOLOGICAL STUDIES[1]

JOHN N. WOLFE,
The Ohio State University

For well over a century ecologists and foresters have included in their reports of investigations of local areas, summaries of climatic data from nearby weather stations. These summaries may reflect the macroclimate of a region, thus serving to locate the area in plains, desert, forest or tundra. But they do not account for the various biotic phenomena described, such as occurrence, growth, survival, succession, reproduction and death of plants and animals. Rarely do the authors make any statements concerning relationships between these factors and the biological phenomena observed in the field. It may be that there are none that are cause and effect relationships.

The meteorological data obtained at Weather Bureau stations form the basis for generalized concepts of phenomena making up a regional climate. These regional climates are clearly recognizable, and in this sense, are comparable to the generalized soil types such as Marbut (15) has recognized in his delineation of the major soil types of the United States. But the pedologists have gone further, mapping local variations in soils within the great divisions. Ohio, for example, lies within one of the nine divisions known as the gray-brown podzolic soils province. But in Licking County alone, 56 types and phases are recognized and mapped (32). In the more deeply dissected terrain of Adams County, 68 types and phases are mapped (24).

Studies of local climatic differences, or microclimatic types, comparable to these studies of the pedologists have scarcely been begun by climatologists, although the local microclimates are similarly varied and complex. Moreover, these local atmospheric conditions are the climates in which plants actually live.

Field reports of ecological investigators invariably include analyses of soil factors, most of which have been directly measured in the problem area. But oddly enough, local climatic conditions have been measured only occasionally within the field of survey. Climatic data from the very beginning of meteorological measurements, have been obtained from regular meteorological stations, and here from instruments housed in "standard shelters," located one to 50 miles from, and at elevations several feet to a mile above or below, the areas studied.

Thornthwaite and Leighly (27) remark that "the climate of a region as determined by means of these standardized observations is more or less of an abstraction." Geiger (9) has called the climate determined through data obtained by these methods "human climate," *i. e.*, climate based on weather elements in which humans are most interested with regard to transportation, physical comfort, recreation, harvesting of crops, sale of merchandise, and the like. In short, it is the weather around our heads, physically and psychologically, and

[1]Publication No. 477, Department of Botany, The Ohio State University.

does not even remotely resemble the weather experienced by plants and animals at our feet.

But whatever the label applied to the interpretation of these enormous quantities of data accumulated at stations all over the world, they have been exceedingly significant in at least three respects:

1. They have resulted in a knowledge of the pattern of "human climate" over large areas, probably reaching the best expression in North America in Thornthwaite's classification (25); and for the world in Köppen's system (13).

2. They have enabled climatologists to compute the variation of climatic factors in different large areas for years, decades and centuries, and also the same area from year to year.

3. They have brought out a recognition of the duration, extent, intensity, and the periodicity, of certain phenomena such as drouth, precipitation and temperature conditions. For example, Visher (30) has utilized Weather Bureau precipitation data as a basis for his maps showing distribution of excessive rainfall. This distribution correlates closely with the Southern Coastal Plain forest formation. Kincer (11, 12) has shown the temperature trend to be upward all over the world during the past century, basing his conclusions on the accumulated data at a number of metropolitan stations with long weather records.[2] Marvin (16) has recognized definite precipitation trends of 50 to 100 years at Boston. Thornthwaite's evaporation-precipitation index maps (26) show a remarkable similarity to the known periodic fluctuations in the boundaries between original forest and prairie, and prairie and grassland formations.

The files of the Weather Bureau also constitute a vast repository of data likely to be of much value when finally analysed and interpreted. In addition to the actual temperature and precipitation data, many cooperative observers have listed quantities of phenological data, such as the times of bird migrations, the breaking of buds, the flowering of plants, the appearance of certain mushrooms and the maturing of various crops. The original records may be a rich source of such data, which, as Wing (33) remarks, "may be better for some wildlife comparisons than the temperature records themselves." The observations of Thomas Mikesell at Wauseon, Ohio, for a period of 40 years are outstanding examples. These are probably the most extensive and complete phenological records in North America, and they have been compiled and published by Smith (22).

In general, however, the Weather Bureau has been most active as a public service through its weather predictions. In fact, its primary function has been the forecasting of weather. The accumulation, analysis and interpretation of climatic data have been secondary because of limitations of available personnel.

USE OF WEATHER BUREAU DATA IN ECOLOGICAL REPORTS

It is not the regional factors, however, that control the behavior of plants and animals that live, grow, reproduce and die in the multitude of different habitats in large biotic areas like deciduous forest, prairie, or tundra.[3] Yet, even the most recent ecological literature is replete with uninterpreted Weather Bureau data. The following are only a few random examples. Gates (8), in his paper on the bogs of northern Lower Michigan, states that "the climatic conditions most closely resemble those of the Weather Bureau station at Cheboygan, Michigan," one to 100 miles north of the various bogs and between two of the largest lakes in North America. This remarkable statement, completely contrary to the findings of Cox (6), is followed by some data from this distant station. Pearson (19)

[2]Studies now in progress in the Botanical Laboratories at The Ohio State University indicate that this trend is not as pronounced in rural areas as it is in metropolitan centers, the source of most of Kincer's data.

[3]For another point of view, see Cain's quotation of Clements (2), pp. 11 and 21.

in his paper on the effect of herbaceous vegetation on the regeneration of *Pinus ponderosa*, cites precipitation data from a station six miles away from the experimental plot. Purer (20), who studied the ecology of the salt marshes along 40 miles of the California coastline, refers to temperature, sunshine and precipitation data recorded at San Diego, 35 miles from the farthest station. Stoeckler and Limstrom (23) published a paper on factors influencing reforestation in northern Wisconsin. The area in which the studies were conducted is 10 miles southwest of the station from which the climatic data were obtained. Brown's meticulous 10-year study of Roan Mountain (1) included data recorded at two stations 15 and 18 miles away, and at elevations 2,535 and 4,710 feet, respectively, below the problem area. Oddly enough, length of day, one of the most significant of ecological factors, is rarely mentioned.

MACRO- VERSUS MICRO-METEOROLOGY

The climatological and ecological literature, however, is not without reports showing that conditions, as measured by Weather Bureau standards, are sometimes astonishingly dissimilar from nearby, or even adjacent, plant and animal habitats. Wolfe, Wareham and Scofield (34) report frost free periods of seven different lengths in different habitats of a mile-long valley in central Ohio, ranging from 124 to 256 days. For the same year (1941), a Weather Bureau station nine miles away recorded a frost free period of 144 days. They also show that the annual minimum temperatures varied in the habitats in the valley from —25° F. to +32.5° F., compared to the official minimum of —18° F. Annual maximum temperatures varied from 76° F. to 120° F., and the dates of the annual maximum temperatures varied from April to August at the different stations.

The same authors report that the date of the last spring frost in 1941 in the valley varied from April 3 to May 25. These dates are almost identical to the official figures for the whole state of Ohio for 1941. At the 88 Ohio stations the last spring frost came between April 2 and May 25 (4). Thus the frost dates of various stations in a small valley less than a mile in length showed as much variation in 1941 as did the whole network of Weather Bureau stations in the state. Data for the first fall frost are even more striking. In the valley the first frost-dates in autumn were recorded from September 26 to December 13. The range for Ohio's 88 stations was October 11 to November 10 (4).

Cox (5), in an intensive four-year study of thermal belts in North Carolina, found, among other things, that the length of the growing season varied from 100 to 232 days at 60 stations. The same author (6), in his pioneer microclimatic study of cranberry bogs in Wisconsin, published a vast amount of soil and air temperature data showing that "great extremes of temperature occur in any bog and there is a wide range of minimum temperature in the same bog," further remarking that when the Weather Bureau station at Lacrosse (20 miles from nearest bog) reports prospective temperatures below 50° F., frost can be expected in the marshes if the night is clear. His report supporting this statement is too detailed for summary here. Malde (14), whose work is in agreement with that of Cox (6), increased the average length of the growing period in Wisconsin bogs from 58 to 118 days by application of sand. The averages are based on an 11-year study. Sinclair (21), working on maximum air temperatures in the desert, found great variation between the levels at 4, 12, 32, 65, 114 and 175 cms. above the soil surface through summer days. Maximum temperature of 122° F. at 4 cms. occurred at 1:00 p. m. At the same hour, the temperature at 175 cm. was 15° lower.

These are only a few examples, but there are many others, some of which are discussed by Geiger (9) in his systematic treatment of "the climate of the layer of air near the ground."

SPATIAL VARIATION IN PRECIPITATION

Spatial variation in rainfall within small areas has been shown by Turnage and Mallore (28), Humphrey (10) and Musson (17) to be very great, sometimes the highest readings differing as much as 30 per cent from the lowest. The numerous maps and tables showing variation in amount of precipitation published by the Muskingum Conservancy Project reveal striking differences in different stations of the Muskingum watershed. The Weather Bureau records themselves, sometimes show great differences in amount of precipitation at stations near each other. The correlation of these figures with biotic phenomena is difficult in light of the data in Table I, from two stations near each other in Muskingum County, Ohio (4).

TABLE I

DIFFERENCES IN AMOUNTS OF PRECIPITATION PER DAY AT PHILO (1) AND PHILO (2)[a]; MUSKINGUM COUNTY, OHIO, IN 1943

Precipitation Difference of:	Number of Days per Month With Varying Amounts of Precipitation												
	Jan.	Feb.	Mar.	Apr.	May	Jun.	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Less than .10 ins	16	15	6	14	14	4	7	5	8	8	10	11	118
Between .11–.25 ins	5	1	5	3	5	3	7	0	1	0	1	0	31
Between .26–.50 ins	1	1	1	2	4	2	2	1	0	1	1	0	16
Between .51–1.00 ins	0	0	3	0	0	1	0	0	0	1	0	0	5
Over 1.00 in	0	0	0	0	0	1[b]	0	2[c]	0	0	0	0	3
Total days ppt	22	17	15	19	23	11	16	8	9	10	12	11	173

[a] Station 2½ miles S.W. of Philo, where (1) is located.
[b] 1.36 ins. at Philo (1); .15 ins. at Philo (2) on June 16.
[c] 1.85 ins. at Philo (1); .40 ins. at Philo (2) on August 4.
1.02 ins. at Philo (2), none at Philo (1) on August 5.

While 68 per cent of the total days with at least a trace of precipitation have essentially the same amounts at the two stations, the differences appear to be ecologically significant, especially when using the data in conjunction with seasonal or short-time investigations. Moreover, the major differences occur in the midst of the so-called growing season. These differences may be averaged and the total annual precipitation at two stations located so close together become nearly identical. But in 1943 the total at Philo (1) was 29.25; at Philo (2) 34.24, with monthly differences of 1.10 and 1.04 inches in June and August respectively.

TABLE II

DIFFERENCES IN PRECIPITATION AT TWO FIRST ORDER WEATHER BUREAU STATIONS AT CINCINNATI, OHIO[a] FOR THE 1943 GROWING SEASON

Precipitation Differences of	Apr.	May	June	July	Aug.	Sept.	Total
Less than .10 ins	17	21	11	9	7	10	75
Between .11–.25 ins	3	2	3	1	1	1	11
Between .26–.50 ins	0	2	0	5	4	2	13
Between .51–1.00 ins	0	0	2	1	0	0	3
Over 1.00 ins	0	0	1[b]	0	0	0	1
Total days with ppt	20	25	17	16	12	13	103

[a] Stations are located at the Abbe Observatory and the Federal Building, about 3.4 miles apart.
[b] Abbe .55 in.; Fed. Bldg. 1.59 ins. on June 10.

While readings of instruments at the cooperative stations may not always be made at exactly the same hour each day, thus inserting error into the daily comparisons, similar results are obtained in comparing two first order stations at Cincinnati. (Table II).

Moreover, these data usually are concerned only with amount. It has long been recognized that time of precipitation, nocturnal or diurnal; the season, type, amount of interception, run-off, and evaporation are also important ecological factors. But total and average precipitation data are all that are usu illy published by ecologists, often from stations 20–50 miles from the problem area. It seems useless, therefore, to cite precipitation data not obtained in the problem area. The precipitation data represented by Fig. 1b, for example, implies a rather uniform distribution through the seasons at Lancaster, Ohio. Figs. 1a, c plainly show that this is not true, and may frequently be misleading.

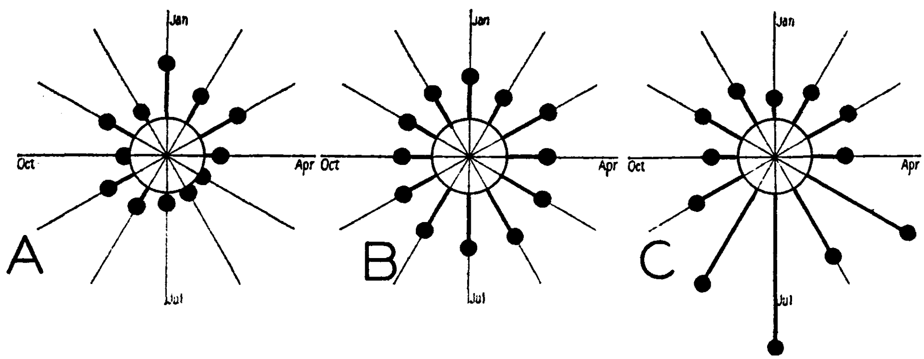

FIG. 1. Precipitation rosettes for Lancaster, Ohio. A, monthly precipitation in 1930, showing year-round drouth conditions; B, mean monthly precipitation giving the impression of rather uniform seasonal distribution; C, monthly precipitation in 1920, showing winter drouth and abundant rainfall during crop growing seasons.

WEATHER BUREAU METHODOLOGY AND PROCEDURES

Weather Bureau methodology and procedures fail to furnish useable ecological data, *i. e.*, data reflecting actual habitat conditions of plants and animals, for several reasons.

1. *Location, Housing and Reading of Instruments:* Not only are the instruments placed five feet above the substrate, but that substrate may be anything from the tar and gravel roof-top of a 90-foot building in a metropolis, to the bluegrass lawn of an airport, or the unsodded terrain of a farmer's barnyard. Moreover, the instruments, located as they are, in standard coops, are sheltered from almost every condition to which plants and animals are subjected, *i. e.*, wind, rain, snow, insolation, nocturnal radiation to the sky, other plants and animals, and the character of the substrate or soil. Thornthwaite and Leighly (27) have observed that "the range in mean monthly minimum temperature [may be] as great within five feet of the ground vertically as in a belt 300 miles from north to south at the standard level." In Table III are some minimum temperature data obtained in the Botanical Gardens at The Ohio State University. Data included in the table were obtained in February and March, 1944. Temperatures at the five-foot level were obtained by using a standard Weather Bureau thermometer, housed in a shelter similar to that of the Weather Bureau type. Utilizing a technique employed by Wolfe, Wareham and Scofield (34), temperatures were also obtained with three thermometers at the eight-inch level

TABLE III

Comparison of Minimum Temperatures Recorded by Variously Exposed Thermometers in the Ohio State University Botanical Garden With Those of Nearby Weather Bureau Stations

1944	Exposed, face up	In therm. holder	Beneath board	Standard shelter	Col's, O., W. Bureau	O. S. U. W. Bureau
Feb. 20	5.0	8.0	14.0	14.0	25	23
Feb. 21	12.0	13.0	19.0	21.5	26	27
Feb. 22	27.5	31.0	29.0	34.0	38	38
Feb. 23	34.5	35.5	35.5	36.5	37	38
Feb. 24	20.5	23.0	29.0	27.0	37	35
Feb. 25	16.0	18.0	22.0	23.5	35	31
Feb. 26	42.0	40.5	43.0	43.5	48	44
Feb. 27	32.0	34.5	37.5	39.5	37	41
Feb. 28	32.0	32.0	33.5	33.5	31	34
Mar. 1	21.0	21.0	23.5	22.5	24	25
Mar. 2	3.0	6.0	12.5	12.5	22	20
Mar. 3	....	19.0	23.5	22.5	32	31
Mar. 5	17.0	15.5	18.0	16.5	18	19

TABLE IV

Distribution, According to Amount, of 415 Consecutive Rainfalls of .05 to .37 Inches, at Lancaster, Ohio

Amount	Number	Amount	Number	Amount	Number
.05	34	.16	11	.27	13
.06	8	.17	4	.28	4
.07	3	.18	13	.29	4
.08	15	.19	12	.30	27
.09	8	.20	21	.31	3
.10	27	.21	14	.32	15
.11	5	.22	9	.33	7
.12	17	.23	7	.34	8
.13	9	.24	8	.35	24
.14	4	.25	28	.36	11
.15	30	.26	12	.37	5

TABLE V

Distribution of Daily Minimum Temperatures Between 28° F. and 36° F. at Lancaster, Ohio, Over a 42-Year Period (October–April)

Month	Temperature °F.									
	28°	29°	30°	31°	32°	33°	34°	35°	36°	Total
October	17	22	29	36	33	40	43	52	55	327
November	54	60	66	44	61	63	50	55	49	502
December	59	47	48	46	65	31	24	45	18	383
January	55	38	60	24	44	29	46	30	26	352
February	42	30	51	35	59	31	31	35	18	332
March	39	65	74	54	72	40	36	45	28	453
April	27	34	51	39	46	42	49	56	37	381
Total	293	296	379	278	380	276	279	318	231	2730
Percent	10.7	10.8	13.8	10.2	13.9	10.1	10.2	11.6	8.4	99.7

above a blue-grass sod. One thermometer was placed face-up, on a platform constructed of redwood; another was attached below the platform; another was placed in a holder described by the above writers, at the edge of the platform (Fig. 2). Temperatures recorded at the Columbus Weather Bureau and the cooperative station at the Ohio State University are included in the table. From these data it is obvious that it is not to be assumed that minimum garden temperatures are similar to temperatures recorded by the Weather Bureau or its cooperative station. On cloudy or rainy nights, the minimum temperatures may vary only a few degrees, but when there is much radiation to the open sky, differences may amount to as much as 12° F., even in the seclusion of standard shelters. Instruments not so sheltered show even greater differences and further experiments may show these figures to be most applicable to indicate the temperature conditions to which the plants are subjected.

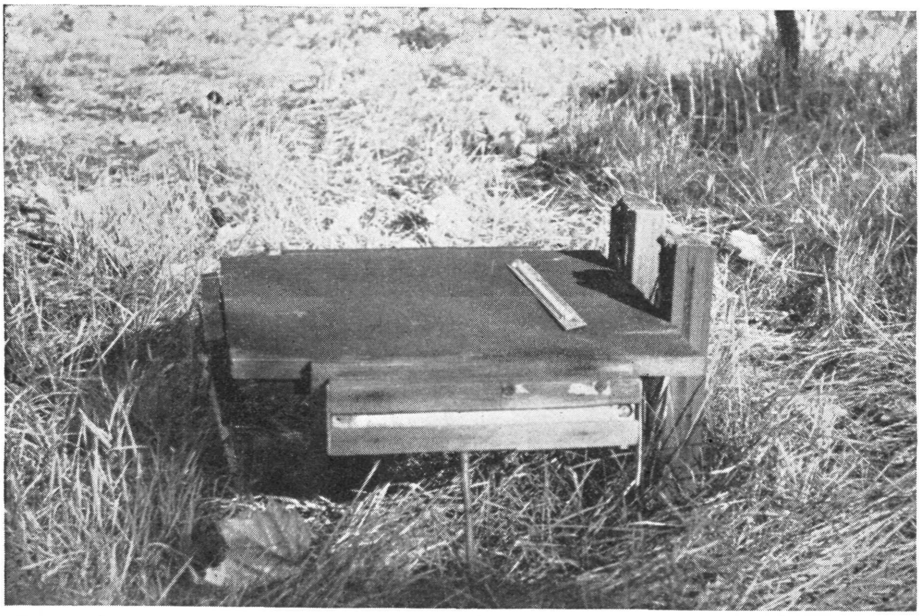

FIG. 2. Photograph of the platform to which variously exposed thermometers were attached to obtain air temperatures at the eight-inch level over a bluegrass sod. Photo by A. Hyder.

The effectiveness of the Weather Bureau set-up in the United States is in great part made possible through the cooperation of 5,000 or more voluntary observers. There are certain features of this system, however, which frequently are sources of slight error. The change of location of the cooperative stations, sometimes entailing significant changes in elevations; lack of uniformity in hours of observation, and breaks in the continuity of the records when the observers retire, are ill, or go on vacation, make certain comparisons of data difficult. Moreover, the data presented in Tables IV and V indicate that the readings may not be exact. All of these, however, may have but little effect on data desirable to the Weather Bureau, nor are they a source of serious error in the compilation of macro-climatic data.

2. *Modification of Observers' Data.* A study of the original records (18) of Ohio cooperative observers on file at the Columbus Weather Bureau, indicates

that some of the observations recorded by the cooperators are subject to modification by their supervisors at the main office. This often leads to false analysis of factors ecologically significant, especially with regard to temperature phenomena.

For example, on the morning of June 23, 1918, at Lancaster, Ohio, the observer recorded a minimum temperature of 40° F., and accompanied the record with a written statement, "Killing frost," adding: "Considerable damage to corn and tender vegetables." The published record (3), however, states that the final spring frost for Lancaster in 1918 was on April 14, 70 days earlier. Moreover, the last "freeze"[4] was recorded on April 25, eleven days after the last official frost. Perhaps no frost occurred the morning of April 25, but it seems unlikely, although entirely possible if surface temperatures were above 32° F. Further study of the Ohio record reveals that this modification is not an uncommon occurrence. (Table VI.)

TABLE VI

LENGTHS OF FROST-FREE PERIODS AT LANCASTER, OHIO, FOR SELECTED YEARS, BASED ON THREE DIFFERENT CRITERIA

Year	Weather Bureau			Observer			32° F. Temp.		
	Last Spring	First Fall	Length in Days	Last Spring	First Fall	Length in Days	Last Sub 32° Spring	First Sub 32° Fall	Length in Days
'05	4/24	10/23	182	None	10/23	....	4/24	10/13	172
'18	4/14	11/2	202	6/23	9/22	91	4/25	11/2	191
'21	4/18	10/13	178	5/1	None	....	4/8	10/13	188
'23	4/26	10/5	162	None	9/14	....	5/9	9/16	130
'26	4/27	11/1	188	None	10/7	....	5/11	10/7	149
'27	4/24	11/6	206	None	9/21	....	5/1	9/21	143
'29	5/8	10/18	163	None	10/18	....	5/8	9/19	134
'32	5/3	10/22	172	5/3	10/22	172	5/3	10/14	164
'35	5/1	10/5	157	None	9/30	....	5/1	9/30	152
'36	4/25	10/28	186	None	10/28	....	4/25	10/3	161
'37	5/11	10/14	156	None	10/8	....	4/12	9/18	159
'38	5/13	10/28	168	5/12	10/28	169	5/13	10/7	147
'39	5/4	10/15	164	5/1	10/15	167	5/4	10/13	162
'40	5/5	10/17	165	5/5	10/17	165	5/5	10/9	157
'41	5/25	10/29	157	None	10/29	....	5/25	10/11	139

Calculation of the length of the frost free period is subject to additional errors because observers may not report frosts when they do occur. Then the officials use the last 32° F. temperature in spring and the first in the fall, but as indicated in Table VI, may also do so whether or not the observer reports frost. The use of two criteria in determining the frost free period leads to some inaccuracy, although as far as macroclimate is concerned, the error may be insignificant. However, whether the frost free period in 1918 at Lancaster was 91, 191 or 202 days, is difficult to determine.

3. *Methods of Compiling and Incompleteness of Data:* The Weather Bureau records have definite limitations as a measure of ecological factors because of the incompleteness of certain observations. When light is measured, it is usually in terms of total hours of sunshine; relative humidity data are reported only three times daily; persistence of snow cover data are fragmentary or lacking; wind

[4]The term "freeze" is used by the Weather Bureau to refer to conditions when the temperature inside the standard shelter is 32° F. or lower. Frost may be recorded when the temperature inside the shelter is as high as 51 F. (Bowling Green, May 12, 1898. (18)). At Lancaster, O., however, the 50-year average date of the first fall frost is Oct. 15 and the average date of the first fall freeze falls six days earlier.

velocities are either not measured or if so, the data are not applicable to ecological problems. It is not uncommon in Hocking County, Ohio, for winds of gale velocities to roar through the pine forests on the uplands, yet on the forest floor of the lower valley, the leaves of plants in the herbaceous layer do not move perceptibly. No satisfactory method of measuring evaporation has ever been developed; precipitation in the form of dew and frost is not measured. Soil temperature and depth of freezing data are lacking and fragmentary.

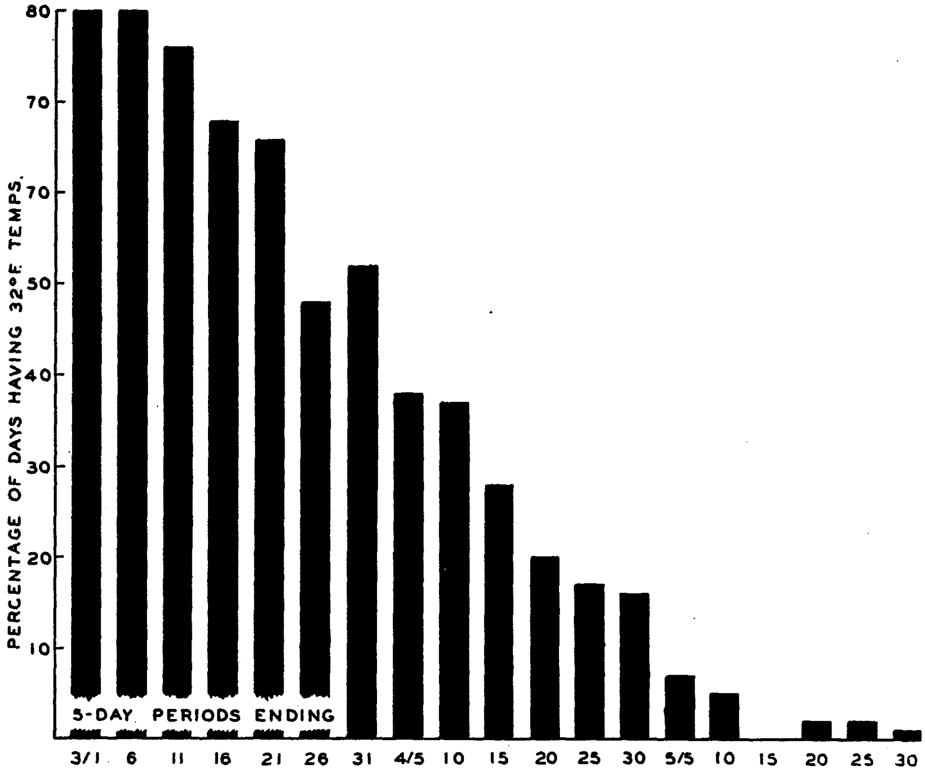

FIG. 3. Frost probabilities for successive five-day periods in spring at Lancaster, Ohio, based on 25-year records from 1910.

Largely because the Weather Bureau data are compiled on a monthly rather than seasonal basis, ecologists publish these data as though each calendar month itself is an ecological factor. Table VII shows how misleading temperature data can be when presented on a monthly basis.

TABLE VII
AVERAGE AND EXTREME TEMPERATURES (°F.) FOR FIVE-DAY PERIODS AT LANCASTER, OHIO, 1910–1935

APRIL	1–5	6–10	11–15	16–20	21–25	26–30	1–30
25 year Average	48.6	49.4	50.7	52.9	52.7	53.9	51.3
25 year avg. maximum	60.4	60.9	62.7	64.5	64.6	65.6	63.1
25 year avg. minimum	36.9	37.9	39.0	40.9	41.1	41.9	39.6
All time maximum[a]	83.0	86.0	89.0	88.0	89.0	92.0	92.0
All time minimum[a]	9.0	19.0	22.0	19.0	21.0	23.0	9.0

[a] 1895–1943.

This is further emphasized when considering probability of frost damage. Figure 3 is based on the frequency of spring frosts during five-day periods over a 25-year span, at Lancaster, Ohio. The percentages indicate the probability of frost during these short periods, from February 26 to May 30.

Although of lesser importance to the ecologist than to the agriculturist, the sub-division of the various states into climatic divisions appears in many cases not to have been done on either a climatic, biotic, or physiographic basis or a combination of the three. Ohio, for example, is divided into "northern," "middle"

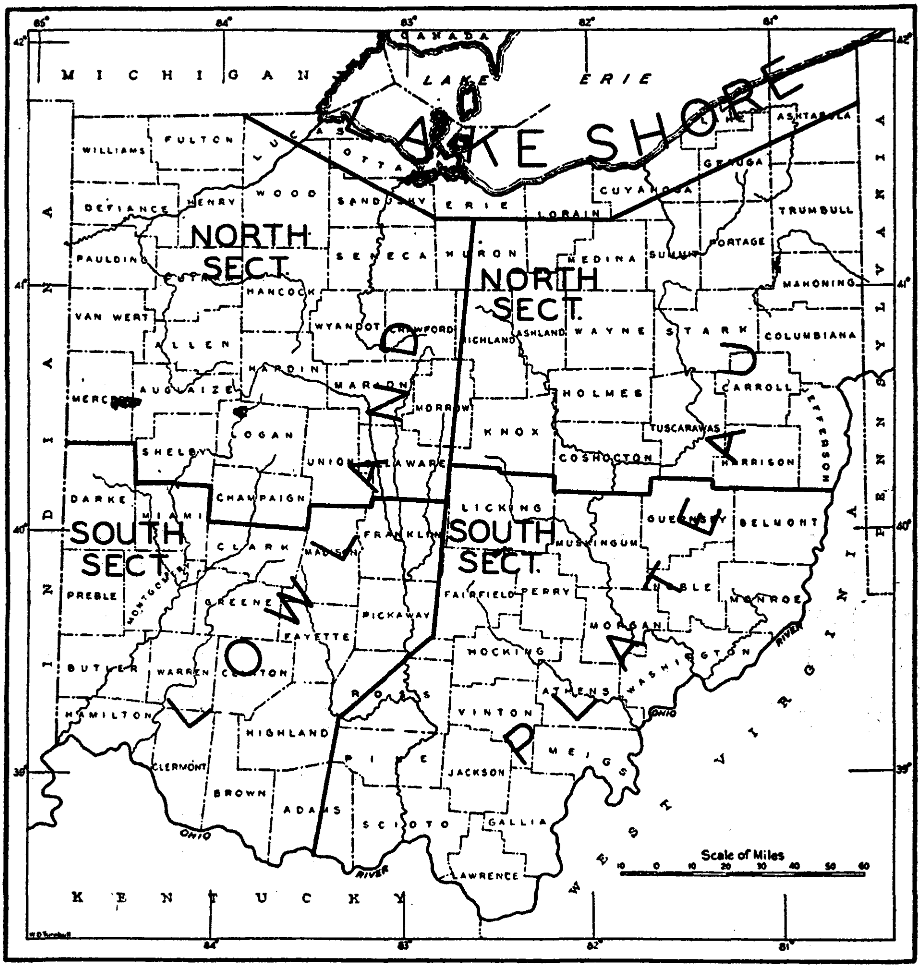

FIG. 4. Suggested subdivision of Ohio for climatic comparisons. This takes into account the effects of the plateau and lake on climate, which physiographic features overshadow the effects of latitude. In western Ohio the influence of physiography is less marked.

and "southern" divisions, apparently on what may be considered a doubtful assumption, stated by Fisher (7) that "probably the greatest variations in the climate [of Ohio] are those incident to latitude." A more desirable subdivision, which would lead to better comparisons, is suggested in Fig. 4.

This analysis of Weather Bureau data, as used by ecologists, is in no way a reflection on the work of the Bureau and its thousands of cooperative observers.

They have contributed abundantly to one phase of human knowledge. Rather, the data seem to emphasize the need for a different approach to climatic and weather problems as related to agriculture, forestry, ecology and conservation. "Knowledge of human climate," as Geiger (9) remarks, "has now reached a stage of tentative finality." With the broad generalizations developed, they stand as a basis from which to work out the variations and trends in the many habitats located within large areas. This is the province of microclimatology.

SOME PROBLEMS OF MICROCLIMATOLOGY

Microclimatology, or ecological meteorology, however, is confronted with a number of major problems which will have to be solved before satisfactory data can be obtained and adequate correlations made with carefully observed biotic phenomena. Four of the principal problems are mentioned below.

1. *Instrumentation.*—The development of new instruments and the modification of old ones is necessary to meet the difficulties connected with the measurement of factors in the habitats. Many present instruments were constructed for laboratory use, or for use in protected shelters, or have been placed where they could be frequently and easily adjusted.

2. *Experimentation in Methods.*—Much needs to be done in determining what methods most accurately measure ecological factors in the field. In a leading ecology textbook there is the remark: "With the aid of a thermometer, the measurement of temperature is an easy task" (31). The reading of a thermometer is easy, but "of what is that reading the temperature?" is another question indeed.

3. *Accumulation of Phenological Data.*—Published records of observations of plants and animals in the habitats where the factors are being measured are notable by their absence. Even though it be assumed that Weather Bureau data reflect actual habitat conditions for a given region, observations relative to date of planting, beginning of growth, time of germination, period of greatest vegetative growth, time of flowering, time of maturation of fruit, quality and quantity of the crop are almost totally lacking or exceedingly fragmentary or unreliable.

4. *Facilities for a Long-Time Research Program.*—Thornthwaite and Leighly (27) have outlined a research program which would attempt to meet these problems as well as many others. They suggest that such a program be connected with a large university, so that space, diverse facilities of the various related science departments, and manpower could be available. This appears to be an excellent method of approaching the present and future problems of ecological meteorology.

SUMMARY

1. Weather Bureau meteorological data have been the basis for the development of climatic concepts, and evidence of climatic trends over large biotic areas such as desert, prairie and forest.

2. Weather Bureau records have been re-published extensively by ecologists in conjunction with ecological studies, but correlation of biotic phenomena with the climatic data has not been explained or demonstrated.

3. There is wide variation between macroclimates as determined from Weather Bureau data and the actual (microclimates) to which biotic communities are subjected and by which they are limited.

4. Weather Bureau data are not applicable when explaining such biotic phenomena as growth, reproduction, succession and death of plants and animals in various habitats of a region.

5. There appears to be an urgent need for direct measurements of microclimatic phenomena in the analysis of many problems of agriculture, forestry, ecology and conservation.

6. Further advances in a knowledge of microclimates depend upon the develop-

ment of new instruments and methods, the accumulation of precise phenological data in the habitats or fields where the factors are being measured, and the establishment of facilities for a long-time research program.

REFERENCES CITED

(1) **Brown, D. M.** The vegetation of Roan Mountain: a phytosociological and successional study. Ecol. Mono. 11: 61–97. 1941.
(2) **Cain, Stanley.** Foundations of plant geography. Harper and Brothers, New York. 1944.
(3) Climatic summary of the United States, Sects. 68, 69, 70, 71. U. S. D. A. 1935.
(4) Climatological Data, Ohio Sect. Weather Bureau, Col's, Ohio, 1931–1944.
(5) **Cox, H. J.** Thermal belts and fruit growing in North Carolina. Mo. Weath. Rev. Sup. No. 19. 1923.
(6) ———. Frost and temperature conditions in the cranberry marshes of Wisconsin. Bull. T., U. S. Weather Bureau. 1910.
(7) **Fisher, John C.** Climate of Ohio. *In*, Climate and Man, Yearbook of Agriculture, 1941. p. 1063. U. S. D. A., Washington, D. C.
(8) **Gates, F. C.** The bogs on northern Lower Michigan. Ecol. Mono., 12: 213–254. 1942.
(9) **Geiger, Rudolph.** Das Klima der bodennahen Luftschicht, Die wissenschaft, 78, Braunschweig, Vieweg. 1927.
(10) **Humphrey, Robert R.** A detailed study of desert rainfall. Ecol. 14: 31–34. 1933.
(11) **Kincer, J. B.** Temperature distribution, extremes and trend tendencies over the earth's surface. *In*, Temperature, its measurement and control in science and industry. Reinhold Publishing Corp., New York. 1941.
(12) ———. Is our climate changing? A study of long-time temperature trends. Mo. Weath. Rev., 61: 251–259. 1933.
(13) **Köppen, Waldimir.** Die Klimate der Erde. W. de Gruyter. 1923.
(14) **Malde, A. G.** Increasing the length of the frost-free period on Wisconsin cranberry bogs by sanding. Mo. Weath. Rev., 50: 197. 1922.
(15) **Marbut, C. F.** The soils of the United States. Atlas of American Ag. Pt. III. U.S.D.A. 1935.
(16) **Marvin, C. F.** Concerning normals, secular trends and climatic changes. Mo. Weath. Rev., 51: 283–390. Aug., 1923.
(17) **Musson, C. T.** Variations in rainfall at H. A. College. Agric. Gaz., New South Wales, Pub. 644.
(18) Original records, Ohio cooperative weather bureau observers, on file at the Columbus, Ohio, office of the United States Weather Bureau.
(19) **Pearson, G. A.** Herbaceous vegetation as a factor in the natural regeneration of ponderosa pine in the southwest. Ecol. Mono., 12: 315–338. 1942.
(20) **Purer, E. A.** Plant ecology of the coastal salt marshland of San Diego County, Calif. Ecol. Mono., 12: 81–111. 1942.
(21) **Sinclair, John G.** Temperatures of soil and air in a desert. Mo. Weath. Rev., 50: 142–144. 1922.
(22) **Smith, J. W.** Phenological dates and meteorological data recorded by Thomas Mikesell between 1873–1912 at Wauseon, Ohio, Mo. Weath. Rev. Sup. No. 2. 23–93. 1915.
(23) **Stoeckler, J. H., and Gustaf Limstrom.** Ecological factors influencing reforestation in northern Wisconsin. Ecol. Mono. 12: 191–212. 1942.
(24) **Taylor, Arthur E., J. T. Miller, W. E. Tharp, Earl D. Fowler, T. C. Green and G. W. Conrey.** Soil survey of Adams county, Ohio. U. S. D. A. Series 1932, No. 29. Sept., 1938.
(25) **Thornthwaite, C. W.** The climates of North America according to a new classification. Geog. Rev., 21: 633–655. 1931.
(26) ———. Atlas of climatic types in the United States, 1900–1939. U. S. D. A. Misc. Pub. 421. Washington, D. C. 1941.
(27) ——— **and John Leighly.** Status and prospects of climatology. Sci. Mon. 57: 457–465. 1943.
(28) **Turnage, W. V., and T. D. Mallory.** An analysis of rainfall in the Sonoran Desert and vicinity. Pub. 529. Carn. Inst., Washington, D. C. 1941.
(29) **Turnage, W. V., and A. L. Hinkley.** Freezing weather in relation to plant distribution in the Sonoran Desert. Ecol. Mono. 8: 529–550. 1938.
(30) **Visher, Stephen S.** Heavy precipitation records. Mo. Weath. Rev. 69: 353–357. 1941.
(31) **Weaver, J. E., and F. E. Clements.** Plant Ecology. p. 357. McGraw-Hill Book Co., New York. 1938.
(32) **Wildermuth, Robert, W. D. Lee, A. H. Paschal and J. G. Steele.** Soil survey of Licking county, Ohio. U. S. D. A. Series 1930, No. 48. Jan., 1938.
(33) **Wing, Leonard.** Freezing and thawing dates of lakes and rivers as phenological indicators. Mo. Weath. Rev. 71: 149–188. 1943.
(34) **Wolfe, John N., Richard T. Wareham, Herbert T. Scofield.** The microclimates of a small valley in central Ohio. Trans. Amer. Geophysical Union, 154–166. 1943.